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A data model for supplying a Data Center with several energy sources

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Abstract—This article presents a data modeling to handle the power flow in a smartgrid. The power flow is studied through RenewSim. It is a simulator dedicated to supply a Data Center which is simultaneously fed by renewable and non-renewable energy sources. Nowadays, the use and optimization of the energy consumption of Data Centers are very broad research areas. The development of energy called “green” and how to use them smartly, becomes an inevitable problematic because of the current ecological considerations. RenewSim is based on the use of several energy sources (electricity supplier, solar panels and batteries). This simulator has a center decision controller. It aims at make clever decisions for the use of heterogeneous sources. The contribution of this article is a data modeling which allows the power redirection by labeled and prioritized the different sources of energy. The priorities and the labels are presented and the results obtained are exposed.

I. INTRODUCTION

Areas such as home automation, smart buildings and cities want to operate largely with renewable energies. Smart grids are part of the implementation of such smart buildings throw Micro-grid. It aims at saving energy and reducing the CO2 foot print. In this article, the use of a smart-grid allows to feed in a green way a Data Center. Nowadays, the running cost of a Data Center is more and more expensive. The utilisation rate and users needs increase day after day (streaming, social network, and in clouds with the on-demand services). It becomes a real problematic because the “brown” energies (non-renewable) do not have an endless capacity. For example, the “Université de Paul Sabatier III” has consumed 148300MWh PE¹ in one year between 2008 and 2009². The European Commission has estimated the Data Center consumption in the european area at 56 billion kW in 2008 and has evaluated 104 billion for 2020³. The use of different energy sources introduces some

¹PE, Primary Energy is used in reference value to represent the energy footprint of a building. The energy vector weighting is set by countries for each sector. $E_p = finalenergies \times energiesvector$

²http://developpementdurable.cnu.fr/img/documents/universites/Fiche_de_synthese_Universite_Paul_Sabatier_Toulouse_III.pdf

³“Code of Conduct on Data Center Energy Efficiency” by the European Commission in October 2008

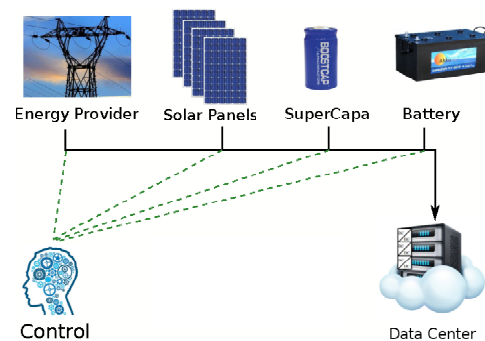


Fig. 1. A SmartGrid Energy sources management example

new problematics related to the energy storage. Many works exist on the battery for load/unload models and their usage in a Data Center [1] [2]. This storage form may be considered as a safety for shortage case. Also, the use of solar panels is complex and unpredictable because it depends on the weather variations.

The Fig.1 presents an architecture example of a Data Center supplied by heterogeneous energy sources and storage capacities. The control component aims at being able to take clever decision for the use of heterogeneous energy sources. Those observations are the article base dedicated to a data modeling for RenewSim.

Ours challenges are to connect several energy sources and destinations together, how to redirect the energy produce by the solar panel in the smartgrid (Battery, Data Center, or supplier), and to take a decision to satisfy the energy cost at the weakest rate. The problematic is how to characterize the heterogeneous electricity sources to make a decision to reduce electricity bills ? In this article we will focus on a modeling for the heterogeneous electricity component. The paper is organized as follows: the Section 2 is the related work on the current simulators and the green Data Center supplied by batteries or solar panels. The section 3 describes

smartgrid, green energies and the simulator RenewSim. The section 4 presents our modeling for RenewSim. The section 5 is the methodology used. The section 6 evaluates the model. Then, the section 7 is the balance sheet of this article and the further works.

II. RELATED WORK

Our approach with RenewSim is to feed a Data Center with renewable energy in a smart way, thanks to a control module. This one aims at optimizing the electric flow and the scheduler of a center of calculation in an electrical network powered by heterogeneous sources. Simgrid [3] is a simulator for distributed applications heterogeneous in distributed environments. It allows the execution of algorithms for scheduling a Data Center[4], the simulation of storage in a Data Center [5] and the use of the DVFS (Dynamic Voltage and Frequency Scaling) in a Data Center [6]. This simulator is in the improvement of the actual application in the field of grids. CloudSim[7], historically based on GridSim[8], is a simulator Cloud Computing of type infrastructure as a Service (IaaS). The architecture of the Data Center is finely modeled and can be easily modified by the user. It integrates the virtualization (migration), the addition of investment policies as well as the energy costs and operation induced. Another version [9] also integrates the DVFS. This simulator is purely dedicated to the internal management of the Data Center. GreenHadoop [10] is an evolution of GreenSolt [11]. It allows the simulation of wind turbines, solar panels. GreenHadoop incorporates the principle of dynamic replication of data to ensure the availability of the latter. A module of the prediction of energy production is present with which the charging of the batteries is managed and incorporates five levels of priorities of jobs (Very High, High, Normal, Low, and very low). These two simulators [11], [10] allow to optimize the consumption of the solar energy but do not propose to optimize simultaneously the energy consumption, and the financial cost. The Simulator RenewSim is a simulator dedicated to the use of solar panels. It uses states to qualify the servers in a Data Center, as in GreenHadoop. It is a simulator dedicated to the co-simulation. It will therefore be able to integrate the version [9] of CloudSim.

III. A MICRO-GRID TO REDUCE THE ENERGY COST

In this section, we will introduce RenewSim a simulator to supply a Data Center. It is a co-simulation tool based on a micro-grid architecture. RenewSim is a simulator for co-simulation based on the use of several energies (renewable or not). It uses batteries, solar panels and electricity suppliers. It aims at managing the power flow in a clever way between the several sources until the Data Center.

The Fig.2 presents an example of a RenewSim architecture. It is possible to plug several sources and destinations. The main source is the solar panels production and the main destination is the Data Center. Each element plugged to the bus is connected to a converter. Those are modules for the conversion of DC/DC or DC/AC. This micro-grid is supervised

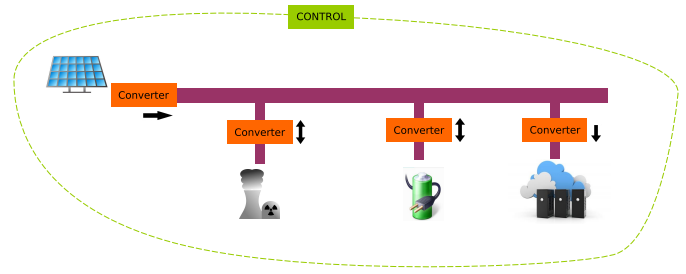


Fig. 2. RenewSim Architecture

by a control module. His role is to find the best possible configuration for both management of the energy flow (feeding the Data Center) and scheduling tasks in the Data Center. This involves to manage the power, the power sold from the solar panels to the suppliers, the power bought or sold to the supplier based on its cost and also the load/unload of the battery. The allocation of tasks depends on their characteristics (CPU and memory capacity, priority, preemptive or not) and the total amount of available energy. The Data Center has the ability to turn on and off the servers and allows tasks migration. RenewSim aims at reducing the energy cost by studying the power flow and the Data Center demand in a decision block.

IV. A MODEL TO IMPROVE RENEWSIM THE CONTROL MODULE

To improve the RenewSim simulator, two possibilities are conceivable: manage the different degrees of freedom or specify the intrinsic behaviour of each block (batteries, solar panels, Data Center, Electric suppliers). Here, the model is based on the first possibility.

A. Freedom degrees

The model aims at being an input of RenewSim to decide which solution costs more, costs less or for example uses more renewable energy. The power asked by the Data Center does not let us a lot freedom degrees. Solar production does not depend on the system. As the data center load, it is a system input and does not have freedom degrees. Production of solar panels depends on the weather and time of day. The freedom degrees will be thanks to the batteries and the electricity suppliers. The supplier price depends of time. During the night the electricity is cheaper than during the day. The degree of freedom is the power of solar panel destination which is stored on the batteries or sold to the power supplier or supplied to the Data Center. Currently, RenewSim promotes renewable energy. What would happen if he favored monetary gain to renewable energy? For example, by promoting the electric suppliers instead of using renewable energy to feed the data center, we get two different functions: night and day.

- 1) Night: purchase energy required to operate the data center, fully charge the batteries from the electrical suppliers.
- 2) Day: Sell to the suppliers the solar overproduction, use the battery in case of underproduction.

For exploiting all the freedom degree, we need to characterize each element: the batteries, the solar panels, the Data Center and the suppliers. The Data Center and the solar panels can only be respectively destination and source. The other could be sources, destination, backup or overflow. The interest of the system is to optimize energy flow. For example, if the system takes a very small amount of energy from the battery to the Data center, the power flow is not efficient and involves too much losses in terms of energy. However, if the system takes a lot of amount of energy from the battery, for example it will be more interesting at time t to take half from the battery and the other half from the supplier, because it could be smarter to keep a amount of energy in the battery.

B. Element Characterization

To take a faster decision based on the freedom degrees, each element of the micro-grid (Fig.2) except the decision module, is described by a model. An element can be a source of energy, a destination, a back-up and an overflow. The main source of RenewSim is solar panels. The destination is the main Data Center. The source and destination are inputs of RenewSim, they leave no degrees of freedom. One is the production Solar (Source) that depends on the weather and the day. The other is the Data Center Demand (Destination). The demand depends on the needs of users and servers at a time t . The batteries and the electric suppliers can be sources, destinations, overflow or backup. The backup allows to get power when the sources cannot answer the Data Center demand (under-production). The overflow allows to store energy when the sources provide more energy required to operate the Data Center (over-production). The table I below presents the modeling.

TABLE I
A MODELING EXAMPLE: HOW TO USE LESS BROWN ENERGY

	Source	Destination	Backup	Overflow
Solar Panels	1	0	0	0
Data Center	0	1	0	0
Battery	1	0	1	1
Supplier	0	0	2	2

Here, in Table I, the battery and solar panels supply the Data Center as sources. In case of under-production, the electric supplier (Backup = 1) feeds the Data Center. In case of over-production, we stock the excess energy in the battery (Overflow = 1). If the battery is full we sell energy to the electricity supplier (Overflow = 2).

TABLE II
A MODELING EXAMPLE: HOW TO FAVOR THE MONEY THAN THE RENEWABLE ENERGY BY DAY

	Source	Destination	Backup	Overflow
Solar Panels	1	0	0	0
Data Center	0	1	0	0
Battery	0	0	1	0
Supplier	0	0	2	1

TABLE III
A MODELING EXAMPLE: HOW TO FAVOR THE MONEY THAN THE RENEWABLE ENERGY BY NIGHT

	Source	Destination	Backup	Overflow
Solar Panels	1	0	0	0
Data Center	0	1	0	0
Battery	0	1	0	0
Supplier	1	0	0	0

The modulation in the tables II and III favor the money than the renewable energy. During the day, the model is as follow (II): RenewSim use the solar panels to supply the Data Center. If there is an over-production of energy (Data Center demand \leq solar panels production) the overfull is sold to the suppliers. If there is an under-production (Data Center demand \geq solar panels production), the lack is taken from the backup 1. Here, it is the battery (unload). If the backup one is empty, the lack is taken from the backup 2 (purchase). Here, it is the supplier.

V. METHODOLOGY

This section presents the environment for the different results (Section VI).

A. Algorithm

The destinations and the sources elements follow the equation 1, with $\sum S_t$ is the sum of all the sources available at time t , and $\sum D_t$ is the sum of all the destinations available at time t . To guarantee the equation 1 in case of over and under production, the equation 2 adds $\sum B_t$, the sum of all the backup resources available at time t , and $\sum O_t$ the sum of all the overfull available.

$$\sum S_t = \sum D_t \quad (1)$$

$$\sum S_t + \sum B_t = \sum D_t + \sum O_t \quad (2)$$

Algorithm 1 Over-Production: $P > 0$

Require: $P > 0$

```

tab_overfull  $\leftarrow$  sort_table_overfull(tab_overfull)
for  $i=0; i; \text{len}(\text{tab\_overfull}); i++$  do
  if tab_overfull[i]_over==true then
    continue;
  end if
  if tab_overfull[i]_enough==true then
    update_tab_overfull(overfull)
  end if
  if tab_overfull[i]_not_enough==true then
    update_tab_overfull
    (tab_overfull[i](storage_available))
  end if
end for

```

In the Algorithm 1, the sum of all the sources is greater than the destinations demand. This is an over-production. So,

for each overfull element, in order of priority, the algorithm stores the over-production. There are three cases: the overfull element is over, the overfull can take all the energies or the overfull can store a part of the over-production.

Algorithm 2 Under-Production: $P < 0$

Require: $P < 0$

```

tab_backup ← sort_table_backup(tab_backup)
for i=0; i; len(tab_backup); i++ do
    if tab_backup[i].empty==true then
        continue;
    end if
    if tab_backup[i].enough==true then
        update_tab_backup(demand)
    end if
    if tab_backup[i].not_enough==true then
        update_tab_backup
        (tab_overfull[i](quantity_available))
    end if
end if
end for

```

In the Algorithm 2, the sum of all the sources is lower than the destinations demand. This is an under-production. So, for each backup element, in order of priority, the algorithm takes the energy asked by the destination. There are three cases: the backup element is empty, the backup can offer all the energies or the backup can offer a part of the demand.

B. Study area

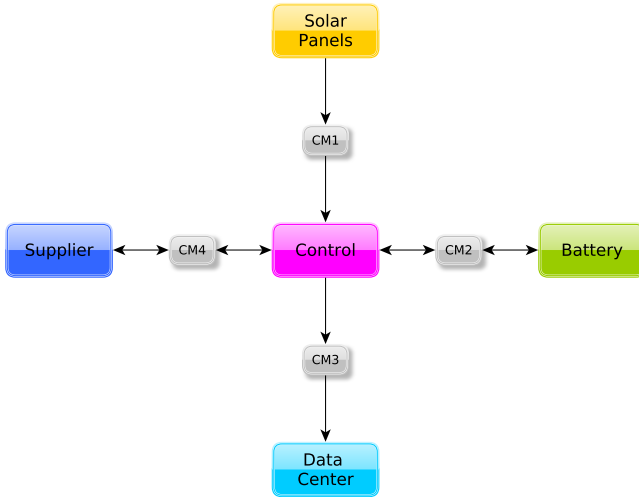


Fig. 3. RenewSim Architecture for the experimentation

For the experiments, the micro-grid used is made of one supplier, one battery, a Data Center and a solar panels park. In the (Fig.3), CM1 to CM4 converters have the respective losses of 15%, 17%, 13% and 14%. The production of solar panels is derived from actual measurements. They come from ADREAM building ⁴. For 48-hours, ADREAM solar produc-

tion provides 1648 measures. The Fig.4 shows two consecutive days of production with some production decline peaks. The decline peaks can be explained by cloud or bad weather at a time t .

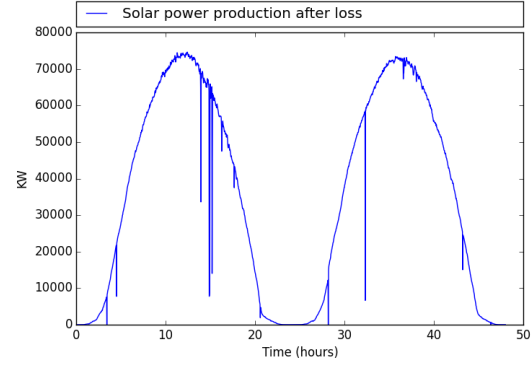


Fig. 4. Solar panel production for the experiments

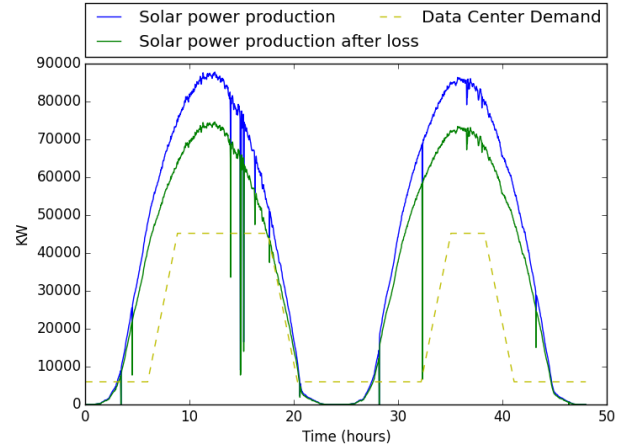


Fig. 5. RenewSim Entries

In Fig.5, the lower bell is the solar production panel after the converter (15% loss). Another input of the system is the Data Center demand (dashed curve). This demand is not known at each time t by the simulator. In the following experiments (section V), the energy costs of the supplier are the following: 0.2366€ per kWh from 8pm to 8am (night) and 0.6173€ per kWh from 8am to 9pm (day).

$$A(t) = P_{ee}(t)/(1 - l) \quad (3)$$

$$V(t) = V(t - 1) + P_{ee}(t) \times (1 - l) \quad (4)$$

The power purchase and sale to the supplier is respectively modeled by the equations 3 and 4 with the power purchased and the power sold with A the power purchased, V the power sold, P_{ee} the power for the supplier before the converter

⁴<https://www.laas.fr/public/en/adream>

module and l converter loss (CM4). The battery has a storage capacity of 10000 joules and a maximum power of 200 kW.

$$E_b(t) = E_b(t-1) + P_{bb} \times \Delta \quad (5)$$

$$E_b(t) = E_b(t-1) - P_b \times \Delta \quad (6)$$

The battery load and unload is respectively modeled by the equations 5 and 6, with t the time, Δ conversion time interval from kW to joules, t the time, P_{bb} the power for the battery after the converter module (CM2), and E_b the energy load into the battery (joules).

VI. RESULTS

In this section, we experiment two different states of our model. The initial state of the solar panel and the power load required by the Data Center is given by the Fig.5

A. Experimentation 1: A renewable model

For this experiment, we used the following modeling: In

TABLE IV
A MODELIZATION EXAMPLE: HOW TO USE LESS BROWN ENERGY

	Source	Destination	Backup	Overflow
Solar Panels	1	0	0	0
Data Center	0	1	0	0
Battery	0	0	1	1
Supplier	0	0	2	2

this case, RenewSim will purchase energy to the supplier only when the sum of all the destinations are upper than the sources (Equation 7) and also if the battery (backup element) is empty or cannot offer all the power (Algorithm 2).

$$\sum S_t < \sum D_t \quad (7)$$

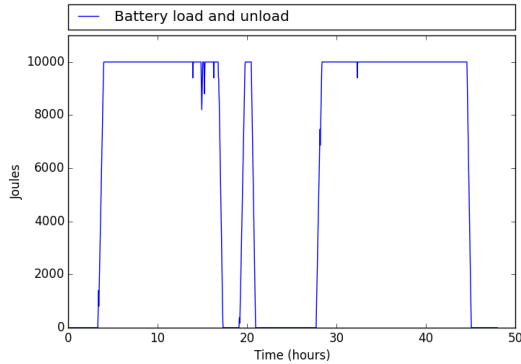


Fig. 6. Exp 1: Battery load at time t during two days

The battery load is represented by Fig.6. The battery can supply the Data Center when the solar production slows down. This is the same noise around $t=15$ to 17 hours we saw in Fig.4).

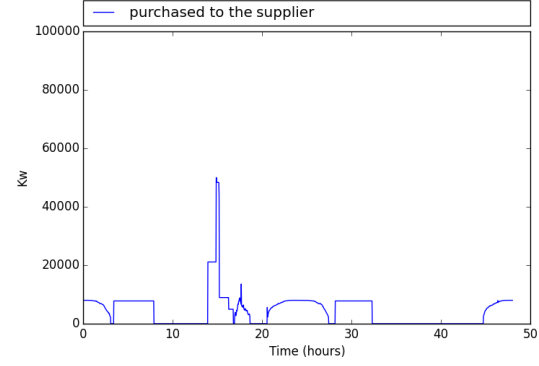


Fig. 7. Exp 1: Sum of all the power purchase to supplier during two days

In Fig.7, this is the sum of all the power purchase to the supplier.

B. Experimentation 2: An economic model

For this experiment, we used the following modelings seen previously: the Table II and III (section IV. B).

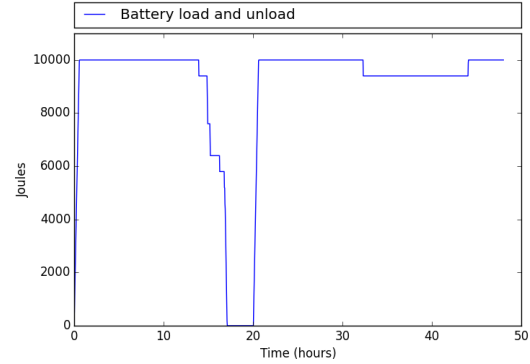


Fig. 8. Exp 2: Battery load at time t during two days

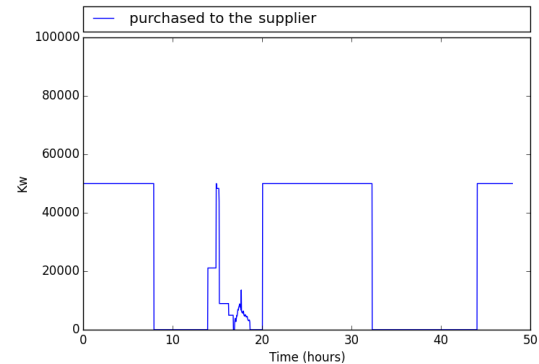


Fig. 9. Exp 2: Sum of all the power purchase to supplier during two days

In this case, RenewSim will always use the battery as a source during the day. It will store energy on it only during the night. RenewSim will never use the battery during the night (Fig.8), because the electricity is cheaper. It will buy the necessary power to supplier when it is cheaper by night (Fig.9). All the over-full of energy is sold to the supplier to earn money. During the second day, RenewSim never bought energy. The battery and the production is enough to feed the Data Center. In the Fig.8, the battery aims at supply the Data Center when the solar panel production is lower (15 hours).

VII. CONCLUSION

The goal of this paper was to present a model to represent each element of a micro-grid and improve the RenewSim control module. The model allows a modular architecture which aims at make clever decision for the use of heterogeneous sources. The contribution of this article is a data model which allows the power redirection by labeled and prioritized the different sources of energy. In the future, this model will allow us to include predictions model and learning machine into the control module of RenewSim. Through two distinct scenarios, the control module can take decision in a purpose: use more renewable energy, or purchased as a low price. This model generalize all the process where we can move the power load, for example, water heater in apartment. There is a sociological study to do in the future to see what is the acceptability of the load shift and how to increase it. The more we come to accept people to increase it, the more we will have savings. Other scenario are possible as use more brown energy in order to keep the battery load for next hour. The RenewSim expansion prospects consist include: multi-objective optimization studies via heuristics, algorithms of learning and predictions (production / use) as well as most successful models. Finally, the purpose of RenewSim is also to be a co-simulation tool allowing communication simulators dedicated to each component.

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